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Reconstructing science networks from the past. Eponyms between malacological authors in the mid-19th century

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Keywords

Eponyms; History of Malacology; Historical Social Networks; Elite; Exponential Random Graph Models

Abstract

Reconstructing scientific networks from the past can be a difficult process. In this paper, we argue that eponyms are a promising way to explore historic relationships between natural scientists using taxonomy. Our empirical case is the emerging community of malacologists in the 19th century. Along the lines of pivotal concepts of social network analysis we interpret eponyms as immaterial goods that resemble the properties of regular social contacts. Utilising Exponential Random Graph Models reveals that the social exchange underlying eponyms follows similar rules as other social relationships such as friendships or collaborations. It is generally characterized by network endogenous structures and homophily. Interestingly, the productivity of authors seems to be well recognised among contemporary researchers and increases the probability of a tie within the network significantly. In addition, we observe an epistemological divide in the malacological research community. Thus even in the 19th century, at a time when science was just emerging as a differentiated social system, epistemological distinctions have been a defining concept for scientific contacts.

1 Introduction*

Collaboration lies at the heart of the scientific endeavour and has received a lot of attention from scholars of various backgrounds for many decades.[1] The relationships that connect scientists are often represented as networks and allow other researchers to derive distinct patterns of disciplines, e.g. how many collaborators a typical scholar has or the underlying routines of the division of labour within a field.[2] Those recurrent patterns of scientific relationships form "invisible colleges"[3] resembling local encounters of leading scholars and their followers, forming intellectual networks across ages and driving academic progress since a long time.[4]

On a micro-level, studies reveal how the formation process of scientific contacts takes place in detail.[5] Yet, most of the explained variance of why people collaborate with each other can be assigned to classic demographic characteristics, starting with varying patterns of collaboration by scholars' age.[6] Another important aspect lies in the geographic proximity that increases the probability to do research together.[7] It is also often argued that informal social networks and collaboration in general increases the productivity of a

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1 Beaver, Donald. 2001. Reflections on scientific collaboration (and its study): past, present, and future*. *Scientrometrics* 52: 365–377; Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration: Part II. Scientific co-authorship, research productivity and visibility in the French scientific elite, 1799–1830. *Scientometrics* 1: 133–149. doi:10.1007/BF02016966; Merton, Robert K. 1973. *The Sociology of Science*. Chicago: The University of Chicago Press.

2 Newman, Mark. 2004. Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences* 101: 5200–5205. doi:10.1073/pnas.0307545100.

3 Bakker, Hans. 2017. Scientific Networks and Invisible Colleges. *The Blackwell Encyclopedia of Sociology.* London: Blackwell. doi:10.1002/9781405165518.wbeoss051.pub2

4 Collins, Randall. 2002. *The Sociology of Philosophies: A Global Theory of Intellectual Change.* Cambridge, Mass.: Belknap Press of Harvard University Press.

5 Genuth, Joel, Ivan Chompalov, and Wesley Shrum. 2000. How Experiments Begin: The Formation of Scientific Collaborations. *Minerva* 38: 311–348.

6 Wang, Wei, Shuo Yu, Teshome Megersa Bekele, Xiangjie Kong, and Feng Xia. 2017. Scientific collaboration patterns vary with scholars' academic ages. *Scientometrics* 112: 329–343. doi:10.1007/s11192-017-2388-9.

7 Ponds, Roderik, Frank van Oort, and Koen Frenken. 2007. The geographical and institutional proximity of research collaboration. *Papers in Regional Science* 86: 423–443. doi:10.1111/j.1435-5957.2007.00126.x.

researcher.[8] Finally, epistemological boundaries play a huge role[9], which create by design many more opportunities for research collaboration *within* one community than between scientists from different fields.

Despite the importance in understanding the composition of research teams and the abundance of studies[10], there are only few historical studies dating back earlier than 1900 due to a variety of data issues like missing documentation or archives, emergence of many disciplines later on, a semi-professional science system, and many more. In this paper, we argue that within biological sciences and therein eponyms provide a great opportunity to study historical social contacts in science. Given the old and rich archival systems established fairly early on in these taxonomical disciplines, we are able to examine many of the personal characteristics we previously cited to be of high relevance for networks of scholars: age, geography, productivity, and affiliation to a certain research community.

In order to test the influence of those characteristics on eponyms, we first provide some background on taxonomy and eponyms in zoological science. After describing the data and methods used in this paper, we address typical questions of research collaboration, e.g. who are the most important authors of that epoch and if an elitist core is identifiable. Building on those descriptive patterns, we run Exponential Random Graph Models[11] to detect homophily in regard to personal characteristics, i.e. to test if one of, or probably even *the*, most guiding principle[12] in social relationships also applies in the social process of eponyms between malacologists. Finally, we discuss our results and possible directions for future research, especially in how eponyms could help scholars to

8 Bozeman, Barry, and Elizabeth Corley. 2004. Scientists' collaborating strategies: implications for scientific and technical human capital. Research Policy 33: 599–616. doi:10.1016/j.respol.2004.01.008. Villanueva-Felez, Africa, Jordi Molas-Gallart, and Alejandro Escribá-Esteve. 2013. Measuring Personal Networks and Their Relationship with Scientific Production. *Minerva* 51: 465–483. doi:10.1007/s11024-013-9239-5.

9 Knorr Cetina, Karin. 2009. *Epistemic Cultures: How the Science make Knowledge*. Harvard University Press.

10 Stokols, Daniel, Kara L. Hall, Brandie K. Taylor, and Richard P. Moser. 2008. The Science of Team Science. *American Journal of Preventive Medicine* 35: S77–S89. doi:10.1016/j.amepre.2008.05.002.

11 Harris, Jenine. 2014. *An Introduction to Exponential Random Graph Modeling*. 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc. doi:10.4135/9781452270135; Robins, Garry, Pip Pattison, Yuval Kalish, and Dean Lusher. 2007. An introduction to exponential random graph (p*) models for social networks. *Social Networks* 29: 173–191. doi:10.1016/j.socnet.2006.08.002.

12 McPherson, Miller, Lynn Smith-Lovin, and James M Cook. 2001. Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology* 27: 415–444. doi:10.1146/annurev.soc.27.1.415.

get a better understanding of the emerging days of professional scientific research.

2 Eponyms as scientific contacts of the past

The role of historical science networks in biological sciences has received at least some attention.[13] However, historical studies in malacology have focused almost exclusively on biographies, bibliographies and lists of new taxa described by individual malacologists. A regularly updated list of these data is available[14] and as such is a great resource. In some biographical works contact networks have been reconstructed.[15] However, neither in-depth studies on contact networks of individuals nor studies of coherent networks have been published (cf. Audibert and Breure, 2017).

Malacology can be seen as an example of a rich field for analysing social contacts represented by eponyms.[16] Superficial data on contacts between malacologists is scattered throughout the literature. Archival studies have been limited to biographical data, and the correspondence archives of malacologists are scarce and ill-explored. Correspondence archives are usually limited to

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13 E.g. Marples, A., and V. R. M. Pickering. 2016. Patron's review: Exploring cultures of collecting in the early modern world. *Archives of Natural History* 43: 1–20. doi:10.3366/anh.2016.0342.

14 Coan, Eugene V., and Alan R. Kabat. 2018. *2,400 years of malacology*. American Malacological Society.

15 E.g. van der Bijl, Bram, Robert Moolenbeek, and Goud Jeroen. 2010. *Matheus Marinus Schepman (1847-1919) and his contributions to malacology*. Leiden: Netherlands Malacological Society; Breure, Abraham S.H., and Wim Backhuys. 2017. Sauveur Abel Aubert Petit de la Saussaye (1792–1870), his malacological work and taxa, with notes on his correspondence. *Archiv für Molluskenkunde International Journal of Malacology* 146: 71–96. doi:10.1127/arch.moll/146/071-096; Breure, Abraham S.H., and Wim Backhuys. 2017. Science networks in action: the collaboration between J.G. Hidalgo and H. Crosse, and the creation of 'Moluscos del Viaje al Pacifico, Univalvos terrestres.' *Iberus* 35: 11–30; Mierzwa-Szymkowiak, D., and Abraham S. H. Breure. 2017. Inside and outside the Neotropics: three Polish naturalists during the late nineteenth and early twentieth centuries. *Archives of Natural History* 44: 151–158. doi:10.3366/anh.2017.0423.

16 Breure, Abraham S.H. 2017. Reconstructing historical egocentric social networks in malacology: is there a link between eponyms and contacts of an author? *Folia conchyliologica*: 3–12.

professionals[17], while those of amateurs are seldom preserved.[18] Preliminary studies of correspondence have shown that a three-fold distinction may be made: (a) the exchange of ideas, (b) the exchange of material (i.e. dry shells or preserved molluscs), and (c) the exchange of formal knowledge (i.e. reprints). Special attention is given to eponymy (dedication by a taxonomist of a new species to a certain person), as this may have played a role in the building of trust during the establishment of the social relationship. Eponyms are used in taxonomy when an author describes a new taxon (usually a new species) for which he uses the name of a person, following the rules of latinisation as given in the International Code on Zoological Nomenclature (ICZN). Eponyms can be given to anyone, but are usually either someone who collected material for study (field collectors) or colleagues (cabinet collectors, authors). Recently the hypothesis was developed that eponyms may serve as a proxy for contact[19], and this has been researched using archival sources and data from literature.[20] Although each author has his 'personal profile' when giving eponyms to others, the case studies hitherto explored show consistently two main target groups for eponyms: field collectors who supplied the material which could be used to describe new species, and cabinet collectors or fellow authors with whom there was contact as evidenced by correspondence. Some examples may help to illustrate this process. The first one relates to Arthur Morelet (1806-1892), who received material collected in Angola by the botanist Friedrich Welwitsch (1806-1872). He identified the material and found several new species, of which he named eight after Welwitsch.[21] Another case study concerns Hippolyte Crosse (1826-1898), director of the French malacological journal at that time, who also had a collection. Breure showed that usually the first eponym was given around the time of the first contact, evidenced by the correspondence archive of Crosse.[22]

While this was all centred on individuals, the science network within the community of malacologists is virtually unexplored. This community consists of persons performing one or more of the following roles: field collector, cabinet collector, and author. This preliminary analysis focusses on the latter role, i.e. the malacological author writing taxonomical papers, and takes into account

17 Breure, Abraham S.H., and Cédric Audibert. 2017a. 'Mon cher Directeur': an inventory of the correspondence addressed to Hippolyte Crosse during his years as director of the 'Journal de conchyliologie.' *Folia conchyliologica*: 3–108.

18 For an exception see: Breure, Abraham S.H. 2015. The malacological handwritings in the autograph collection of the Ph. Dautzenberg archives, Brussels. *Folia conchyliologica*: 1–111.

19 Breure, *Reconstructing historical egocentric social networks in malacology*.

20 Breure, *The malacological handwritings in the autograph collection of the Ph. Dautzenberg archives*; Breure, *Reconstructing historical egocentric social networks in malacology*.

21 Breure, Abraham S.H., Cédric Audibert, and Jonathan D. Ablett. 2018. *Pierre Marie Arthur Morelet (1809-1892) and his contributions to malacology*. Nederlandse Malacologische Vereniging.

22 Breure, *Reconstructing historical egocentric social networks in malacology*, Figure 2.

that two (sub)communities may be distinguished: authors dealing with fossil shells (palaeontologists), and those dealing with Recent shells. The distinction between these two groups is, however, not complete and a partial overlap exists. The aim of this paper is to present a first analysis of relations between malacological authors during the period 1850-1870. How was the community of authors structured during that period? Where was the core of malacological activities situated? Was there an 'elite' of malacological authors? We will address these questions by looking at the amount of active relationships of authors per country, whether these relationships were nationally or internationally oriented, and, more generally, whether the eponyms are structured in a similar way as "regular" social contacts like friendships or collaborations.

3 Methods: Social Network Analysis and Exponential Random Graph Models

As source of data for this analysis the publication of Ruhoff was used, covering the period 1850-1870. [23] Data on authors have been extracted from this paper, listing the number of publications during this period, the number of pages (for the elite authors; see below), the number of co-authored publications, and the number of co-authors involved. The number of pages from co-authored publications is divided between the co-authors. In total 701 authors are listed in Ruhoff's paper, of which 490 published new species. All species listed in her Index to Species were checked for possible eponyms against the authors included and against Coan and Kabat[24] to exclude eponyms that had been given posthumously (eponyms published in the year after the person's death are, however, still counted due to possible time lag in publication). The data on the authors are summarised in the supplementary information for this article.[25]

For each eponym (1) the publishing author ('source') and (2) the author named in the taxon ('target'). The interactions between authors are divided into (3) eponyms, exchange of material (when the manuscript name of an author has been introduced in a work of a third author), or a joint publication. Further (4) the number of eponyms, exchanges, or co-authored papers, (5) the year of the first eponym within the period 1850-1870, (6) ibidem the last year, (7) the country where the source was residing according to current political-administrative borders, and (8) ibidem for the target. Some authors relocated

[23] Ruhoff, F.A. 1980. Index to the species of Mollusca introduced from 1850 to 1870. *Smithsonian Contributions to Zoology*: 1–640.

[24] Coan and Kabat, *2,400 years of malacology*.

[25] This and other supplementary data is available in a Figshare repository: doi:10.6084/m9.figshare.10322114.

during this period, and when this is known the year of relocation is taken into account; otherwise the country of residence where the person lived for the majority of time during this period was chosen. Eponyms derived from first names (e.g., *arthuri*, *ceciliae*, *sophiae*) are excluded. If the eponym could be applicable for more than one person with that surname, care was taken to check the original source or to take contextual information into consideration. Authors known to have published (mainly) on fossils are indicated with 'Palaeontologist'. A summary of relations of source nodes at national scale and across boundaries is given in Supplementary Information S1; transdisciplinary relations are summarised in S2. Geographically the following aggregations have been made: European – all countries west of Russia and Turkey; Americas – countries of North and South America, and the Caribbean; 3A – countries in Africa, Asia (including Russia), and Australia.

Although it is understood that some authors may be underrepresented due to the period chosen (especially those authors active during the years immediately before 1850 and after 1870), these limits have been chosen due to practical reasons. To take this into account, the age of the author in 1850 (if known) has been recorded. The selection of productive authors ('elite') was done in two steps: first a ranking was made on the total number of publications during the period analysed; secondly authors were selected who contributed to 80% of the total publications and a final ranking was made using their total number of pages published during the period (derived from Ruhoff or from WorldCat).[26]

In addition to descriptive network characteristics, we are analysing possible effects of homophily in malacologists' eponyms. For this purpose, endogenous parameters that are well-known to structure networks (triangles etc.) have to be controlled in order to reveal signals of nodal or dyadic attributes. This is most often done in Exponential Random Graph Models (ERGM)[27], which are stochastic representations of empirical networks. The goal of an ERGM is to explain the global structure of a network with few local parameters. In doing so, it resembles a multivariate model in which endogenous network parameters can be considered, which most often exhibit the largest effects on the constitution of a network. To avoid the problem of multicollinearity - which is by definition always present in a network due to interdependence of its parts - we simulate in ERGMs a large number of random graphs to compute average network statistics and compare those with the empirical network.

Nevertheless, the general mechanics of an ERGM are very much alike to a logistic regression, the binary outcome variable for a network model being

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[26] The dataset was analysed using Cytoscape 3.5.1 (www.cytoscape.org; Shannon et al. 2003) and RStudio (2018).

[27] Harris, *An Introduction to Exponential Random Graph Modeling*; Robins *et al.*, *An introduction to exponential random graph (p*) models for social networks*.

"having a tie (or not)". Formally, we estimate the probability P of a specific realisation of a network x out of a set of all possible networks X with n vertices: $P(X = x) = exp\ (\theta z(x))/K(\theta)$, with $z(x)$ as network or actor (dyadic) characteristics, θ coefficients, and K as a normalising constant. Yet unlike a deterministic logistic regression, an ERGM estimates the probability of observing a specific network x by exploring its deviation from a large number of random networks, in order to circumvent the problem of multicollinearity. The algorithm converges if the coefficients θ of the network characteristics $z(x)$ generate graphs which are reasonable close to the empirical realisation.[28] Hence, θ can be interpreted as the log-odds of an individual tie. In so doing, the change statistic z is increasing or decreasing the probability of a tie in the specific network x by θ than it would be expected by chance alone (and which we approximate by large quantity of simulated random graphs).

Most of the effects in which social scientists are interested in are the attributes of social entities, mostly size and homophily. Given its composition, ERGMs allow us to test if specific nodal or dyadic attributes influence ties' probability in a certain graph significantly net of endogenous network effects. For instance, we can directly test whether homophily in regard to gender, country of birth or discipline is important for interactions at a conference. In addition, we can also model if the presence or absence of a tie depends on a nodal attribute, i.e. the likelihood of interactions increases (or decreases) with an attribute. These attributes can also be dyadic terms and refer to the status or qualities of an edge. It is also important to note that in order to reduce complexity and improve the convergence of the ERGMs we do not consider direction in the ERGMs and also include authors with more than 5 relationships to concentrate on leading scholars forming the "invisible college" of emerging malacology. This does not alter, however, the exploration of the structural effects of homophily and productivity in regard to being part of the malacological network of eponyms.

4 Mapping the field of historic malacology

In overview, the network shows a rather densely connected 476 nodes, with two heavily linked areas, whereby palaeontological authors gather mostly in one cluster (Figure 1. Further descriptives are also provided in Table 1). We explore this network by its authors' attributes.

28 Cf. further details, for instance, Harris, *An Introduction to Exponential Random Graph Modeling*.

Geography

During the period 1850-1870 a total of 458 malacological authors were active and which could be included in the dataset, of which 83 (18%) were non-European. Of these authors 178 were assigned as palaeontologists, of which 118 gave eponyms to others or exchanged material. In total there were 1822 relationships during the study period, 1578 (87%) by European authors, 219 (12%) by authors from the Americas, the rest from other parts of the world. Within Europe, the countries with the most active authors in terms of relationships were France, Germany, the United Kingdom, and Switzerland (respectively 41%, 20%, 16%, 8% of the European total); see also Supplementary Information S3. Relationships with a palaeontological author as source were 673 (37%), the rest were from authors devoted to recent species or partly describing fossil species. The split between national and international contacts is 52/48% (respectively 53/47% for palaeontologists, and 51/49% for other authors). Countries with relatively high percentages of national contacts were the United States (73%), France (68%), and the United Kingdom (53%).

Network Properties	
Number of Nodes	476
Number of Edges	1822
Average Path Length	3.26
Average Cluster Coefficient	0.13
Modularity	0.41

Table 1. Network descriptives.

Communities

Within the total group, two 'communities' may be recognised: Recent and palaeontological authors, respectively. 'Recent authors' study molluscs that are still extant, while the 'palaeontologists' group studies fossils. There is only a small overlap between the two groups, and authors have been attributed to the group where most of their publications are related to. Of the 1149 relations of the Recent authors group, 1007 (88%) were within this community. For the palaeontological authors this was 443 of a total of 673 (66%). Between the two communities respectively 230 and 142 were initiated by palaeontological and

Recent authors. This is underlined by the high modularity of the network (cf. Table 1), which stems from the compartmentalisation of the malacological research community.[29]

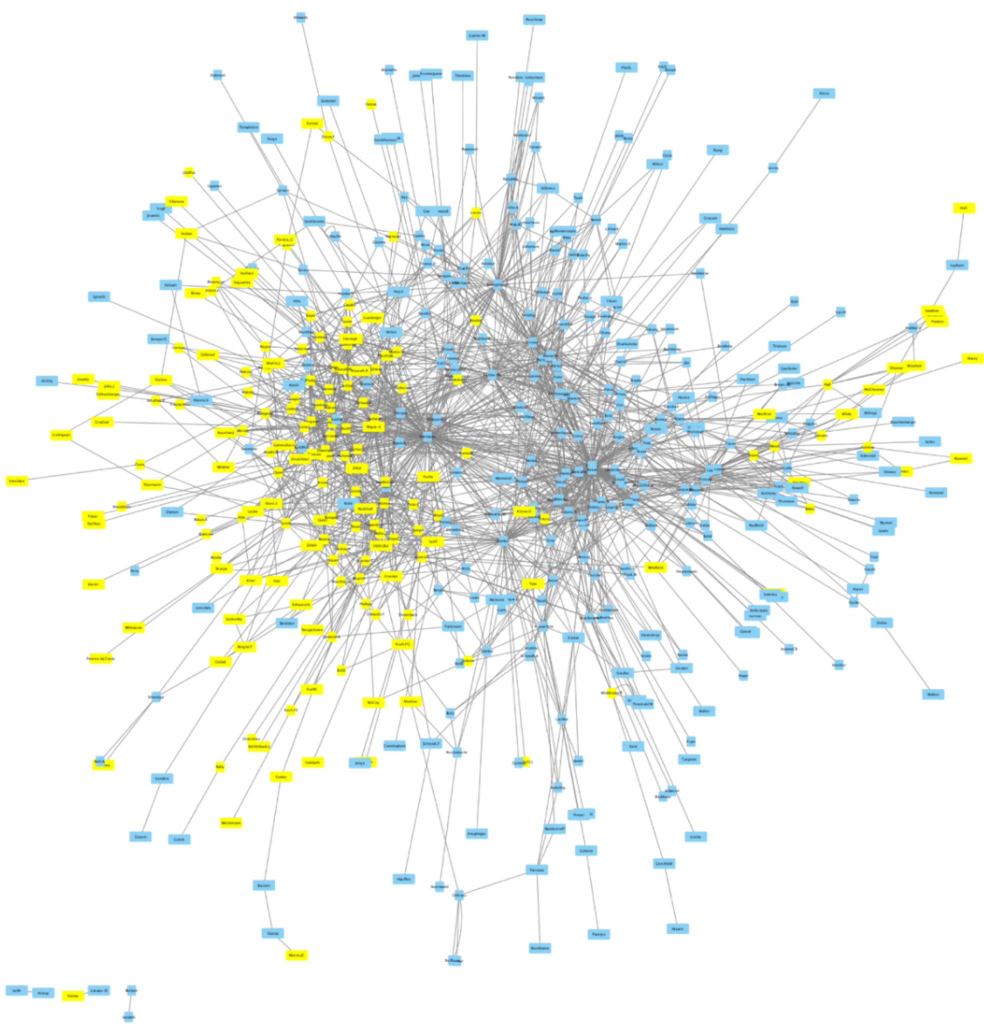

Figure 1. Overview of the total network. Blue boxes are authors who worked on extant species, yellow boxes are those who published on fossils.[30]

[29] Newman, Mark 2006. Modularity and Community Structure in Networks. *Proceedings of the National Academy of Sciences* 103: 8577-8582. doi:10.1073/pnas.0601602103.

[30] A higher resolution version of this graph is available on Figshare: doi:10.6084/m9.figshare.10807163.

Productivity

To identify the core of the malacological authors, a selection was made based on their productivity. This resulted in a subset of 113 authors (hereafter 'elite'), of which 28 (25%) were non-European; 18 were assigned as palaeontologists. Of the 85 Europe-based authors of these 'elite', 31% were from France, 24% from Germany, 23% came from the United Kingdom, and 6% from Switzerland. These authors had in total 546 relations, of which the split between national and international contacts is 43/57% (for palaeontological authors 50/50%).

Age

Because we considered only the period 1850-1870, authors were of differing age. As far as biographical data (cf. again S2) allows we have taken age into account but the ERGM analysis shows there is only a weak and negative age homophily, i.e. being of the same cohort has almost no effect in relation to eponyms.

5 Which attributes structure eponyms?

In order to consider homophily net of other network effects and, hence, test if eponyms are structured by nationality, age, productivity or research community, we utilise Exponential Random Graph Modeling (Table 2). In doing so, we first have to consider the "base probability" of having a tie in our network, which is rather unlikely in our network and can be calculated by $1 - 1/(1 + exp\ (-5.29))$ which gives us a 0.05 probability of having a tie ("edges" in Table 2). The effect corresponds to the density of the network, or in other words: the "ground-truth" of having a tie without considering anything else. Two other distinct effects are considered in order to account for the endogenous network structure: the number of degrees of each actor and the geometrically weighted edgewise shared partner. The former is counting the number of nodes with 2 and 3 degrees and adds them to the network statistic $z(x)$. The latter is taking into account that most social networks are characterised by many triangles, i.e. shared partners. The parameter gwesp does not only account for a simple triangle between A-B-C but also whether A and B share multiple partners, e.g. D, E, F, etc. Since the influence of sharing the *i*-th partner is assumed to be lower than if there are only few shared partners, a decay parameter α is added (after some exploration 0.01 provided the best fit). The higher its value, the more do nodes with more shared partners contribute to the statistic (Snijders et al. 2006).[31]

	(1)	(2)
Edges	-5.035***	-5.259***
	(0.127)	(0.134)
Degree2	1.245***	1.129***
	(0.195)	(0.190)
Degree3	0.603**	0.522**
	(0.198)	(0.197)
gwesp (fixed)	0.958***	1.003***
	(0.072)	(0.076)
HomeCountry (nodematch)	1.368***	1.328***
	(0.065)	(0.063)
Age (nodecov)	-0.001	0.001
	(0.001)	(0.001)
Age (absdiff)	-0.009**	-0.010**
	(0.003)	(0.003)
Pubs (nodecov)	0.012***	0.011***
	(0.001)	(0.001)
Recent community (edgecov)		1.691***
		(0.123)
Akaike Inf. Crit.	7,166.108	7,009.753
Bayesian Inf. Crit.	7,235.364	7,087.665

*p<0.05; **p<0.01; ***p<0.001
Note: Standard deviation is reported in parentheses. Network endogenous effects are written in lower letters, node and edge attributes start with a capital letter. Utilized ERGM functions are reported in parentheses next to variables.

Table 2. Results of ERGM (probability of having a tie).

31 Snijders, Tom A. B., Philippa E. Pattison, Garry L. Robins, and Mark S. Handcock. 2006. New Specifications for Exponential Random Graph Models. *Sociological Methodology* 36: 99–153. doi:10.1111/j.1467-9531.2006.00176.x.

As in almost all social networks, degree and gwesp are strong and significantly positive and improve the fit of our model considerably. Thus even scientific contacts in the 19th century indicated by eponyms follow the "social law" of transitivity and shared relationships. However, at the core of our research interest lie network exogenous effects, especially homophily. Starting with national homophily, we observe a strong tendency of eponyms to be distributed within a nation. Considering all else equal, the chance of having a tie between people with the same nationality is 1.9%, i.e. the chance of having a relationship rises almost by the factor 4 for fellow countrymen. Homophily in regard to nationality is by far the strongest effect among the node attributes. Interestingly, there is no effect of age homophily which we could detect. Other than Wang and colleagues[32] we find no age-dependent effects in terms of being in the same cohort, at least not *ceteris paribus* and net of the other exogenous and endogenous effects included in the model.

In addition to those homophily effects, we also consider if having more publications is increasing the probability of a tie within the eponyms in order to test a possible effect of productivity. And indeed, with more publications rises the probability of having a tie, though only modestly. Each publication improves the chance of being part of the eponyms network by approximately 1.2 percent of the "raw" probability indicated by edges. Thus, for instance, having 10 publications means the probability of being part of the eponyms networks rises by 12 percent, again, *ceteris paribus* and net of all other included effects.

In model 2 we introduce an edge-covariate consisting of the same network, but only considering relationships of one of the communities ("recent"). This exhibits a strong effect and implies a homophily of "sorts", so that eponyms within the same research community have a much higher likelihood than across boundaries. The importance of the effect is also underlined by the improvement in model quality as indicated by AIC and BIC.

32 Wang *et al.*, *Scientific collaboration patterns vary with scholars' academic ages*.

6 Discussion

Since this study is based on eponyms used by authors, it is relevant to stress that each author has a 'personal profile for eponymy', i.e. some authors give relatively more eponyms than others. Although this is a weakness, it is inevitable due to lack of (complete) correspondence being archived for all authors. Multiple eponyms per person have been taken into account, but our analysis is limited to author-author eponyms (see below for author-collector eponyms). Breure has shown that in taxonomy, eponyms may be considered as a proxy for contact.[33] Yet, the nature of this contact may vary, e.g. from gathering additional material for study to exchange of reprints. In this paper, we assume that cases of eponymy resulted in operative collaboration, which may only be tested if complete correspondence archives are preserved. These contacts may, however, also be seen as potential collaboration opportunities; contact formation logically precedes nurturing collaborative relations and are at the core of intellectual networks since ages.[34] In addition, Bozeman and Corley (2004) have formulated a theory which assumes researchers engage in collaboration to enhance their human capital. This implies viewing collaboration strategically to create new synergies in knowledge, increase visibility of publications.[35] Collaboration between scientists was in the nineteenth century far from being so omnipresent as today, and in our dataset we found only 89 pairs of authors (i.e. 0,05% of all relations in our dataset) who actually collaborated as co-authors. Yet one may presume the same social mechanisms (like mutual interest or acquired characteristics like occupation or education) stimulated contacts and eventually collaboration. This equals homophily[36], sometimes specified as specialty homophily.[37] Evans et al. also found strong support for geographical constraints, i.e. collaborations are more likely to involve scholars that are geographically co-located.[38] Already Beaver and Rosen listed spatial propinquity as one of the motives for collaboration.[39] This is also reflected in our results where several countries exhibit a relatively high percentage of national contacts. The size of a country and the less advanced means of communication

33 Breure, *Reconstructing historical egocentric social networks in malacology*.

34 Collins, *The Sociology of Philosophies*.

35 Iglič, Hajdeja, *et al*. 2017. With whom do researchers collaborate and why? *Scientometrics* 112: 153–174. doi:10.1007/s11192-017-2386-y.

36 McPherson *et al*., *Birds of a Feather*.

37 Wang, *et al*.. 2017. *Scientific collaboration patterns vary with scholars' academic ages*.

38 Evans, T.S., R. Lambiotte, and P. Panzarasa. 2011. Community structure and patterns of scientific collaboration in business and management. Scientometrics 89: 381–396. doi:10.1007/s11192-011-0439-1.

39 Beaver, Donald, and R. Rosen. 1978. Studies in scientific collaboration: Part I. The professional origins of scientific co-authorship. *Scientometrics* 1: 65–84. doi:10.1007/BF02016840.

during the study period may also be factors at play, but an in-depth analysis of these factors is beyond the scope of this paper.

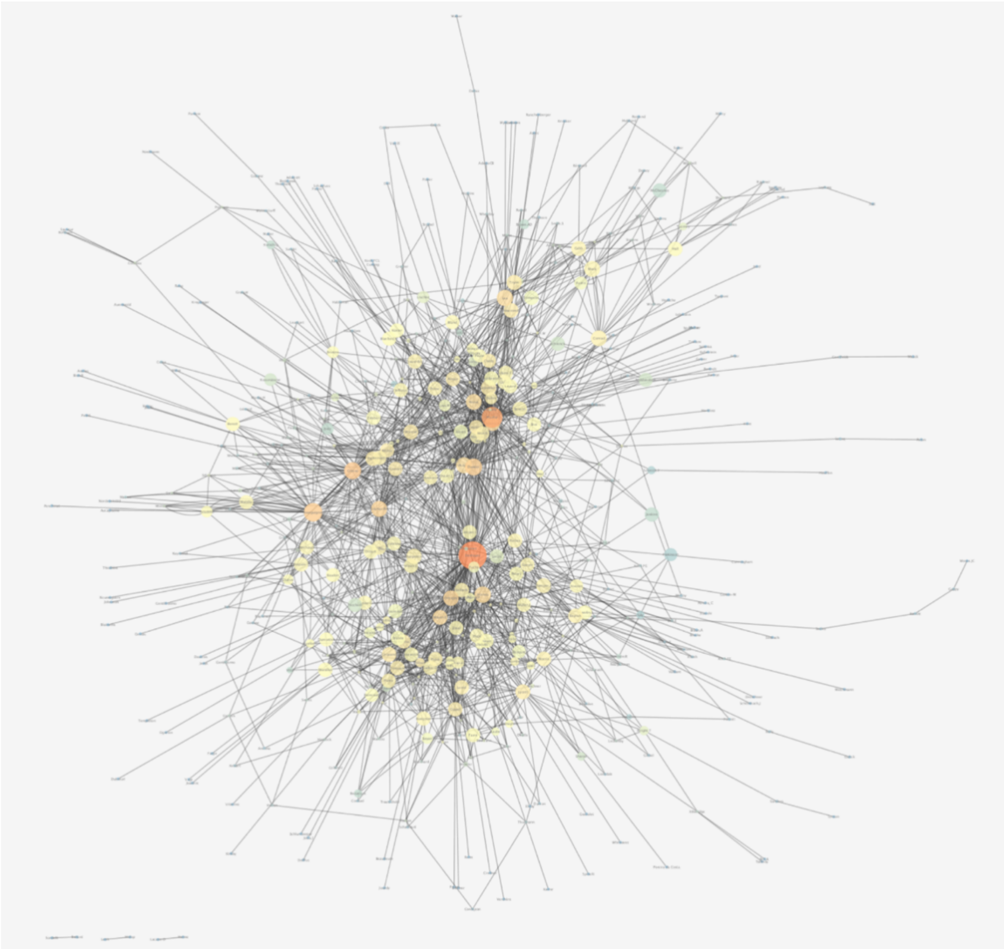

Figure 2. Elite malacologists, 1850-1870. Network showing the most influential authors based on Betweenness Centrality (darker colour is greater BC) and Edge Count (larger circle is higher EC).[40]

[40] A higher resolution version of this graph is available on Figshare: doi:10.6084/m9.figshare.10807160.

When society is viewed "as a market in which people exchange all variety of goods and ideas in pursuit of their interests"[41], gifts of eponyms may be considered as an immaterial good that initiate or reinforce the 'trust-building loop'[42] necessary for maintaining contact or collaboration. As these authors showed, building trust is a cyclical process which builds on itself incrementally. Multiple eponyms, especially if they were given or exchanged over time, may thus reflect this process. But this process can be equally reinforced by sending reprints or material, both actions which are not easily visibly unless there are archival sources to provide evidence.

Our results may also be viewed as analogous to Madaan and Jolad, who studied scientific collaboration and observed that "collaboration between scientists is increasing with time and few numbers of scholars publish a large number of papers while most of the authors publish a small number of papers, which is consistent with Lotka's law on frequency of publications".[43] The findings presented in the previous section on the 'elite' group fits with this statement.

To explore this group of elite authors further, we provide an overview of the most central authors in Figure 2 and Table 3. The "betweenness" of an author is thereby an indicator of influence and who controls the flow of information between most others. The 20 most influential authors show an interesting mix of scholars in different stages of their career, with a number of young 'rising stars' and relatively few 'old stars'. According to Iglič et al.[44] "the longer researchers engage in research, the more knowledge and skills they accumulate. Furthermore, the larger the number of potential collaborators, since engaging in past collaborations, the greater the access to social capital". But according to van Rijnsoever et al.[45], after approximately 20 years of an active research career, collaborative activity starts decreasing and results in an inverted U-shaped relationship between experience and collaboration. These findings are based on current-day situations and cannot be compared directly with the historical situation in our study. Collaboration in a nineteenth century setting has to be

41 Burt, Ronald S. 2001. The network structure of social capital. Research in Organizational Bahaviour 22: 345–423.

42 Vangen, Siv, and Chris Huxham. 2003. Nurturing collaborative relations: Building trust in interorganizational collaboration. *Journal of Applied Behavorial Science* 39: 5–31. doi:10.1177/0021886303253179.

43 Madaan, Gaurav, and Shivakumar Jolad. 2014. Evolution of scientific collaboration networks. *IEEE International Conference on Big Data*. doi:10.1109/BigData.2014.7004346.

44 Iglič et al., *With whom do researchers collaborate and why?*

45 Rijnoever, Frank J. van, Laurens K. Kessels, and Rens L.J. Vandenberg, 2008. A resource-based view on the interactions of university researchers. *Research Policy* 37: 1255-1266. doi:10.1016/j.respol.2008.04.020.

Author	B	Nationality	N	Age
Deshayes	0.15639624	FR	37	54
Pfeiffer	0.07707799	DE	206	46
Bourguignat	0.0510438	FR	42	21
Crosse	0.03512731	FR	124	24
Dunker	0.03495205	DE	29	41
Hörnes	0.02944485	AT	6	35
Lea	0.02626771	US	113	58
Fischer.PH	0.02436345	FR	115	15
Philippi	0.0242428	CL	33	42
Meek	0.02300076	US	34	33
Conrad	0.02253792	US	82	47
Reeve	0.02134736	UK	21	36
Carpenter.P	0.01859395	UK	35	31
d'Orbigny	0.01778389	FR	9	48
Adams.A	0.01580836	UK	125	30
Charpentier	0.01536733	CH	1	64
Tryon	0.01425264	US	52	12
Morelet	0.01237858	FR	41	41
Lycett	0.01218458	UK	15	46
Semper.J	0.01144716	DE	3	?

Table 3. Overview of elite authors.

interpreted with contextual information. In addition, the relatively strong homophily in the Recent / Palaeo communities was an unexpected result in our study. We have found no mentioning of this phenomenon in literature on nineteenth century scholarly activities.

7 Conclusion

In the mid-nineteenth century the field of malacologists was relatively limited with 476 authors who published one or more publications during the period 1850-1870. The world of malacology at that time was mainly a 'Europe-centred' world. The main countries with active authors were France (135), Germany (72), and the United Kingdom (68). Viewing eponyms as social contacts, we investigated several typical properties of social networks. Homophily is known to be one of the prevailing forces to structure social relationships. Given the limited data resources, it is less explored in historic periods and has not been considered at all in the context of taxonomic (zoological) systematics.

Utilising ERGMs revealed that the social exchange underlying eponyms follows similar rules as other social relationships like friendships [46] or collaborations.[47] Especially those two sorts of social contacts are well-explored and mainly characterised by network endogenous structures and homophily.[48] Interestingly, the productivity of authors seems to be well recognised among contemporary researchers and increases the probability of a tie within the network significantly. At the same time, we can observe a differentiation between relationships of Recent and fossil shells, indicating a epistemological divide in the research community. Thus already in the 19th century and at a time when science was just emerging as a differentiated social system [49] epistemological distinctions seem to be a defining concept for scientific contacts.

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46 Heidler, Richard, Markus Gamper, Andreas Herz and Florian Eßer. 2014. Relationship patterns in the 19th century: The friendship network in a German boys' school class from 1880 to 1881 revisited. *Social Networks*, 37: 1-13. doi:10.1016/j.socnet.2013.11.001; Wimmer, Andreas and Kevin Lewis. 2010. Beyond and below racial homophily, ERG models of friendship networks documented on Facebook. *American Journal of Sociology* 116, 583–642. doi:10.1086/653658.

47 Zhang, Chenwei, Yi Bu, and Ying Ding. 2018. Understanding scientific collaboration from the perspective of collaborators and their network structures. *Journal of the Association for Information Science and Technology* 69, 72–86. doi:10.9776/16470.

48 McPherson *et al.*, *Birds of a Feather*.

49 Allen, David Elliston. 1994. *The naturalist in Britain: a social history*. Princeton, NJ: Princeton Univ. Press, p.292.

Taken together, the structure and effects of the network strongly confirm that eponyms can be interpreted as social contacts as suggested by Breure.[50]

Several alternative avenues are possible for further research, both in-depth or extending the scope. For instance, some of the authors in our dataset clearly had a link to (or at least a preference for) a certain journal, and there may be also links to learned societies. This was beyond the scope of our current study, but may reveal interesting networks once examined. Also the exploration of citation networks may shed light on the geographies of reception of scientific papers and books. While in current-day practice of bibliometrics this is facilitated by digital sources and explicit reference lists, the lack of these in nineteenth century literature makes this a more challenging task. In addition, a counter-test with a dataset on the same community would underline the validity of our results.

Furthermore, Beaver and Rosen found a link of collaboration with professionalisation, and according to their data[51] co-authoring was nearly non-existent before 1800 in the field of natural history. During Napoleonic times French scientists institutionalised themselves on a grand scale, soon followed by scientists in Germany and England. The development of malacology during the nineteenth century deserves further study in the light of collaboration and professionalisation.[52] When describing species, authors often mentioned the name of the collector. According to Secord this served to enhance the reliability of the information and to deflect any challenge over the accuracy of information away from the author to the source of information.[53] Such field collectors often had connections to more than one scientist (often in their home country), but studies of such multi-level networks of authors c.q. cabinet collectors with field collectors could shed more light on development of these ‘webs of transfer’.

Closely linked to this topic is the shift between amateurs and professionals in time. According to Shapin the boundaries between the professional scientific community and mere amateurs had been fairly well defined in most areas of sciences by the late nineteenth and early twentieth century.[54] There are several

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50 Breure, *Reconstructing historical egocentric social networks in malacology*.

51 Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration Part III. Professionalization and the natural history of modern scientific Co-Authorship. *Scientrometrics* 1: 231–245.

52 See also the work of Kretschmer and Kretschmer (2013) and Kretschmer et al. (2015) on collaboration and graphical representation.

53 Secord, Anne. 1994. Corresponding interests: artisans and gentlemen in nineteenth-century natural history. *The British Journal for the History of Science* 27: 383–408. doi:10.1017/S0007087400032416.

54 Shapin, Steven. 1982. History of science and its sociological reconstructions. *History of Science*: 157–211, p.273.

other studies about professionalisation in certain disciplines.[55] Breure has shown a malacological example in the late 19th / early 20th century, but a wider perspective for malacologists is needed and a study extending backwards could fill a gap.[56] Beaver and Rosen have shown that in the 19th century, specialisation gradually increased, but 'conceptual revolutions' (like Darwin's publication in 1859 on evolution) accelerated the professionalisation (in this case for biology) and "such revolutions were factors in eliminating amateurs from scientific research".[57] Taxonomy, however, was during those years predominantly a science which demanded no or relatively few instruments nor laboratory equipment. Our hypothesis is therefore that the percentage of amateurs in relation to professionals which had a paid position at a museum or institution remained relatively high at the end of the nineteenth century.

This brings us to longitudinal extension of the current study (e.g., 1800-1820, 1900-1920). To what extent will our current outcomes result in a changed perspective when we take a longer time frame into account? For instance, Elias noted a change in occupation and demography between the 1750s and the end of the 19th century when he studied the data of coleopterists.[58] If a similar dataset for malacologists would be available it may reveal further insights of the early days of scientific research.

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55 Porter, Roy. 1978. Gentlemen and Geology: the Emergence of a Scientific Career, 1660–1920*. *The Historical Journal* 21: 809. doi:10.1017/S0018246X78000024; Shortt, S E D. 1983. Physicians, science, and status: issues in the professionalization of Anglo-American medicine in the nineteenth century. *Medical History* 27: 51–68. doi:10.1017/S0025727300042265.

56 Breure, A.S.H. 2016. Philippe Dautzenberg (1849-1935) and his time, towards the reconstruction of an ancient science network. *Basteria*: 47–58.

57 Beaver and Rosen, *Studies in scientific collaboration: Part II*.

58 Elias, Scott A. A brief history of the changing occupations and demographies of coleaopterists from the 18th through the 20th century. Journal of the History of Biology 47: 213–242. doi:10.1007/s10739-013-9365-9

8 References

Allen, David Elliston. 1994. *The naturalist in Britain: a social history*. Princeton, NJ: Princeton Univ. Press.

Bakker, Hans. 2017. Scientific Networks and Invisible Colleges. *The Blackwell Encyclopedia of Sociology.* London: Blackwell. doi:10.1002/9781405165518.wbeoss051.pub2

Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration: Part II. Scientific co-authorship, research productivity and visibility in the French scientific elite, 1799–1830. *Scientometrics* 1: 133–149. doi:10.1007/BF02016966.

Beaver, Donald, and R. Rosen. 1978. Studies in scientific collaboration: Part I. The professional origins of scientific co-authorship. *Scientometrics* 1: 65–84. doi:10.1007/BF02016840.

Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration Part III. Professionalization and the natural history of modern scientific Co-Authorship. *Scientrometrics* 1: 231–245.

Beaver, Donald. 2001. Reflections on scientific collaboration (and its study): past, present, and future*. *Scientrometrics* 52: 365–377.

Bijl, Bram van der, Robert Moolenbeek, and Goud Jeroen. 2010. *Matheus Marinus Schepman (1847-1919) and his contributions to malacology*. Leiden: Netherlands Malacological Society

Bozeman, Barry, and Elizabeth Corley. 2004. Scientists' collaborating strategies: implications for scientific and technical human capital. Research Policy 33: 599–616. doi:10.1016/j.respol.2004.01.008.

Breure, Abraham S.H., and Wim Backhuys. 2017. Sauveur Abel Aubert Petit de la Saussaye (1792–1870), his malacological work and taxa, with notes on his correspondence. *Archiv für Molluskenkunde International Journal of Malacology* 146: 71–96. doi:10.1127/arch.moll/146/071-096.

Breure, Abraham S.H. 2015. The malacological handwritings in the autograph collection of the Ph. Dautzenberg archives, Brussels. *Folia conchyliologica*: 1–111.

Breure, Abraham S.H. 2017. Reconstructing historical egocentric social networks in malacology: is there a link between eponyms and contacts of an author? *Folia conchyliologica*: 3–12.

Breure, Abraham S.H., and Cédric Audibert. 2017a. 'Mon cher Directeur': an inventory of the correspondence addressed to Hippolyte Crosse during his years as director of the 'Journal de conchyliologie.' *Folia conchyliologica*: 3–108.

Breure, Abraham S.H., and Wim Backhuys. 2017. Science networks in action: the collaboration between J.G. Hidalgo and H. Crosse, and the creation of 'Moluscos del Viaje al Pacifico, Univalvos terrestres.' *Iberus* 35: 11–30.

Breure, A.S.H. 2016. Philippe Dautzenberg (1849-1935) and his time, towards the reconstruction of an ancient science network. *Basteria*: 47–58.

Breure, Abraham S.H., Cédric Audibert, and Jonathan D. Ablett. 2018. *Pierre Marie Arthur Morelet (1809-1892) and his contributions to malacology*. Nederlandse Malacologische Vereniging.

Burt, Ronald S. 2001. The network structure of social capital. Research in Organizational Bahaviour 22: 345–423.

Carpenter, Russell Lant. 1880. *Memoirs of the life and work of Philip Pearsall Carpenter, chiefly derived from his letters.* London,: [s.n.]. doi:10.5962/bhl.title.87586.

Coan, Eugene V., and Alan R. Kabat. 2018. *2,400 years of malacology*. American Malacological Society.

Collins, Randall. 2002. *The Sociology of Philosophies: A Global Theory of Intellectual Change.* Cambridge, Mass.: Belknap Press of Harvard University Press.

Elias, Scott A. A brief history of the changing occupations and demographies of coleaopterists from the 18th through the 20th century. Journal of the History of Biology 47: 213–242. doi:10.1007/s10739-013-9365-9.

Evans, T.S., R. Lambiotte, and P. Panzarasa.2011. Community structure and patterns of scientific collaboration in business and management. Scientometrics 89: 381–396. doi:10.1007/s11192-011-0439-1.

Genuth, Joel, Ivan Chompalov, and Wesley Shrum. 2000. How Experiments Begin: The Formation of Scientific Collaborations. *Minerva* 38: 311–348.

Harris, Jenine. 2014. *An Introduction to Exponential Random Graph Modeling*. 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc. doi:10.4135/9781452270135.

Heidler, Richard, Markus Gamper, Andreas Herz and Florian Eßer. 2014. Relationship patterns in the 19th century: The friendship network in a German boys' school class from 1880 to 1881 revisited. *Social Networks*, 37: 1-13. doi:10.1016/j.socnet.2013.11.001

Iglič, Hajdeja, *et al*. 2017. With whom do researchers collaborate and why? *Scientometrics* 112: 153–174. doi:10.1007/s11192-017-2386-y.

Knorr Cetina, Karin. 2009. *Epistemic Cultures: How the Science make Knowledge*. Harvard University Press.

Kretschmer, Hildrun, Donald Beaver, Bulent Ozel, and Theo Kretschmer. 2015. Who is collaborating with whom? Part I. Mathematical model and methods for empirical testing. *Journal of Informetrics* 9: 359–372. doi:10.1016/j.joi.2015.01.004.

Kretschmer, Hildrun, and Theo Kretschmer. 2013. Who Is Collaborating with Whom in Science? Explanation of a Fundamental Principle. *Social Networking* 02: 99–137. doi:10.4236/sn.2013.23011.

Madaan, Gaurav, and Shivakumar Jolad. 2014. Evolution of scientific collaboration networks. *IEEE International Conference on Big Data*. doi:10.1109/BigData.2014.7004346

Marples, A., and V. R. M. Pickering. 2016. Patron's review: Exploring cultures of collecting in the early modern world. *Archives of Natural History* 43: 1–20. doi:10.3366/anh.2016.0342.

McPherson, Miller, Lynn Smith-Lovin, and James M Cook. 2001. Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology* 27: 415–444. doi:10.1146/annurev.soc.27.1.415.

Merton, Robert K. 1973. *The Sociology of Science*. Chicago: The University of Chicago Press.

Mierzwa-Szymkowiak, D., and Abraham S. H. Breure. 2017. Inside and outside the Neotropics: three Polish naturalists during the late nineteenth and early twentieth centuries. *Archives of Natural History* 44: 151–158. doi:10.3366/anh.2017.0423.

Newman, Mark. 2004. Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences* 101: 5200–5205. doi:10.1073/pnas.0307545100.

Newman, Mark. 2006. Modularity and Community Structure in Networks. *Proceedings of the National Academy of Sciences* 103: 8577-8582. doi:10.1073/pnas.0601602103.

Ponds, Roderik, Frank van Oort, and Koen Frenken. 2007. The geographical and institutional proximity of research collaboration. *Papers in Regional Science* 86: 423–443. doi:10.1111/j.1435-5957.2007.00126.x.

Porter, Roy. 1978. Gentlemen and Geology: the Emergence of a Scientific Career, 1660–1920*. *The Historical Journal* 21: 809. doi:10.1017/S0018246X78000024.

Rijnoever, Frank J. van, Laurens K. Kessels, and Rens L.J. Vandenberg, 2008. A resource-based view on the interactions of university researchers. *Research Policy* 37: 1255-1266. doi:10.1016/j.respol.2008.04.020

Robins, Garry, Pip Pattison, Yuval Kalish, and Dean Lusher. 2007. An introduction to exponential random graph (p*) models for social networks. *Social Networks* 29: 173–191. doi:10.1016/j.socnet.2006.08.002.

RStudio Team (2018). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. http://www.rstudio.com/.

Ruhoff, F.A. 1980. Index to the species of Mollusca introduced from 1850 to 1870. *Smithsonian Contributions to Zoology*: 1–640.

Secord, Anne. 1994. Corresponding interests: artisans and gentlemen in nineteenth-century natural history. *The British Journal for the History of Science* 27: 383–408. doi:10.1017/S0007087400032416.

Shannon, P., A. Markiel, O. Ozier, N.S. Baliga, J.T. Wang, D. Ramage, N. Amin, B. Schwikowski, and T. Ideker. 2003. Cytoscape: A Software Environment for Integrated Models of Biomolecular Interaction Networks. *Genome Research* 13: 2498–2504. doi:10.1101/gr.1239303.

Shapin, Steven. 1982. History of science and its sociological reconstructions. *History of Science*: 157–211.

Shortt, S E D. 1983. Physicians, science, and status: issues in the professionalization of Anglo-American medicine in the nineteenth century. *Medical History* 27: 51–68. doi:10.1017/S0025727300042265.

Snijders, Tom A. B., Philippa E. Pattison, Garry L. Robins, and Mark S. Handcock. 2006. New Specifications for Exponential Random Graph Models. *Sociological Methodology* 36: 99–153. doi:10.1111/j.1467-9531.2006.00176.x.

Stokols, Daniel, Kara L. Hall, Brandie K. Taylor, and Richard P. Moser. 2008. The Science of Team Science. *American Journal of Preventive Medicine* 35: S77–S89. doi:10.1016/j.amepre.2008.05.002.

Vangen, Siv, and Chris Huxham. 2003. Nurturing collaborative relations: Building trust in interorganizational collaboration. *Journal of Applied Behavorial Science* 39: 5–31. doi:10.1177/0021886303253179.

Villanueva-Felez, Africa, Jordi Molas-Gallart, and Alejandro Escribá-Esteve. 2013. Measuring Personal Networks and Their Relationship with Scientific Production. *Minerva* 51: 465–483. doi:10.1007/s11024-013-9239-5.

Wang, Wei, Shuo Yu, Teshome Megersa Bekele, Xiangjie Kong, and Feng Xia. 2017. Scientific collaboration patterns vary with scholars' academic ages. *Scientometrics* 112: 329–343. doi:10.1007/s11192-017-2388-9.

Wimmer, Andreas and Kevin Lewis. 2010. Beyond and below racial homophily, ERG models of friendship networks documented on Facebook. *American Journal of Sociology* 116, 583–642. doi:10.1086/653658

Zhang, Chenwei, Yi Bu, and Ying Ding. 2018. Understanding scientific collaboration from the perspective of collaborators and their network structures. *Journal of the Association for Information Science and Technology* 69, 72–86. doi:10.9776/16470.

9 Supplementary files

The following files are available in Figshare repositories:

Details of authors used in the analysis: BreureHeiberger_Appendix_1: doi:10.6084/m9.figshare.10322114

Overview of relations of source nodes at national scale and international: Table S2: doi:10.6084/m9.figshare.10322114

Transdisciplinarity in interrelations between communities of Recent and palaeontological authors: Table S3: doi:10.6084/m9.figshare.10322114

Figure 1 (Network1-600dpi): doi:10.6084/m9.figshare.10807163

Figure 2 (Network2-600dpi): doi:10.6084/m9.figshare.10807160.